Atmospheric and Climate Sciences, **2012, 2, 307-321**
http://dx.doi.org/10.4236/acs.2012.23028 Published Online July 2012 (http://www.SciRP.org/journal/acs)

Variability of Wintertime Surface Air Temperature over the Kingdom of Saudi Arabia

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Received January 22, 2012; revised March 17, 2012; accepted April 17, 2012

ABSTRACT

Variability of wintertime surface air temperature (SAT) in the Kingdom of Saudi Arabia (KSA) is studied. The study is based on time series over thirty one years in length (1978-2008). For the analysis, we use the coefficient of variability (COV) Mann-Kendal statistical test, running mean and cumulative annual mean (CAM). The coefficient of variability (COV) for wintertime SAT decreases gradually from the north to the south of KSA. The higher values for COV occur in northern and northeastern KSA; there are due to the effect of the traveling Mediterranean depressions and their interaction with the inverted-V shape trough of the Sudan low. The relationship between COV and latitude is highly significant, while with longitude it is not significant. The Mann-Kendal statistical test illustrates that positive trends (warming) in wintertime SAT series occurs over the all stations, and that the trends are significant at middle and southern regions of KSA. Recent warming has only occurred during the last two decades at most stations. While cooling in the wintertime SAT appears for the short period of about 5 years, 1978-1983 and 1988-1992. These trends are consistence with trends in the global mean SAT. The results obtained from CAW lead to the conclusion that the thermic regime is modifying in the KSA. This dramatic enhancement, occurred at the beginning of the year 1993, is reflected in net modification in the SAT time series. The analysis of the SAT also shows a significant warming trend after the year 1997 with a rate of 0.03˚C/year.

Keywords: Winter Temperature; Saudi Arabia; Coefficient of Variability; Trends; Cumulative Annual Mean

1. Introduction

Changes in climatic variability continue to be major global issues, not only for the present generation, but also for future generations. One aspect of climate change is change in variability of weather elements, such as SAT. The SAT database has been extensively reviewed on several earlier occasions, most notably by [1-3]. Recently many researchers [4-8] have investigated the trends of climate variables and the characteristics of the climate change. Adaptation to climate change and efforts to mitigate the impacts of climate change need to emphasize not only changes in long-term mean weather attributes, but also trends in the variability of climatic parameters [9]. Given that climatic conditions evidently vary from one period to another, variability is an integral part of climate change. Consequently, response strategies and adaptations to climatic change, both at the regional and global levels, must address climatic variability. [6] has recently concluded that global warming is unequivocal. Observed to occur concurrently are changes in the regional climate in different parts of the world. The trends of regional temperature variations are important aspects of the baseline against which the potential effects of climate change should be assessed [6]. On a global scale, climatologically studies indicate an increase of 0.3˚C - 0.6˚C of the surface air temperature (0.5˚C - 0.7˚C for the Northern Hemisphere) since 1865 [10]. Climate scientists have concluded that: 1) The earth's surface air temperature increased by about 0.6˚C during the 20th century; and 2) The temperature augmentation was highest during the 1990s (Jones, *et al*., 1999). The study of [11] indicates that there a gradual warming until about 1940, cooling (1940-1970) and a second warming trend begins about 1970 in land surface air temperature. They pointed out that the recent 1976-2000 warming was largely globally synchronous but was more pronounced in the Northern Hemisphere continents during winter and spring. Wintertime surface air temperature is an issue of great concern, as its variability and specially extreme events have important economical and social implications. The successive periods of global warming, cooling and warming in the 20th century show distinctive patterns of temperature change suggestive of roles for both climate forcing and dynamical variability [12]. In the Arabian Peninsula, investigations of long-term variations and trends in temperature data are not receiving enough attention even though, these countries suffer serious environmental, agricultural and water resources problems.

In this work, the behavior of wintertime SAT over KSA since 1978 is examined with regard to persistence, non-linear trends and inter-annual and inter-decadal variations. Observation dataset and its homogeneity are described in Sections 2 and 3 respectively. Section 4 describes the methods that used, while Section 5 contains the results together with a discussion and studying the wintertime SAT changes and variability over KSA. Finally conclusions are drawn in Section 6.

2. Homogeneity

Lack of homogeneity in data series creates a big problem for studying time series. The time series of a climatological variable can only be said to be homogenous where the variability is caused by variations in weather and climate [13]. However, long time series without artificial changes in their statistical characteristics are rare [14]. Non-homogeneities may be caused by relocations of instruments or changes of instruments, observers and observation practices, etc. Slow changes of the surroundings of the observation site may gradually cause non-homogeneities, e.g. the case of urbanization. The timing and size of significant non-homogeneities can be estimated with statistical tests. The authors here used the short-cut Bartlett test [15] to examine the homogeneity of the surface air temperature series at designated stations. The short-cut Bartlett test of homogeneity of variance for winter air temperature is applied by dividing the series into k equal sub-periods, where $k \geq 2$. In each of these sub-periods the sample variance is calculated thus; $S_k = \frac{1}{n}\left\{\sum x_i - \frac{1}{n}\left(\sum x_i\right)^2\right\}$. Where the summations range over the n values of the series in the sub-period k. Let $S^2_{\max}$ and $S^2_{\min}$ denote the maximum and the minimum values of S^2_k, respectively. The 95% significance points ratio $S^2_{\max}/S^2_{\min}$ can be obtained by comparing this ratio with the values given in Biometrika Table 31 [16]. All time series used are found to be homogenous as shown in **Table 1**.

Table 1. Bartlet test (short-cut) result for the KSA stations (*n* is the number of terms in each sub-period *k*, and *k* is the number of the sub-period).

Station	Period	n	k	95% Significance point	Homogeneity
Turaif	31	15	3	5.34	1.53
Guriat	24	12	2	3.50	1.06
Arar	31	15	3	5.34	1.50
Al-Jouf	31	15	3	5.34	1.46
Rafha	31	15	3	5.34	1.48
Tabouk	31	15	3	5.34	1.55
Al-Qaysumah	31	15	3	5.34	1.45
Hail	31	15	3	5.34	1.54
Gassim	31	15	3	5.34	1.52
Dhahran	31	15	3	5.34	1.56
Wejh	31	15	3	5.34	1.60
Al-Ahsa	24	12	2	3.50	1.26
Riyadh	31	15	3	5.34	1.56
Madina	31	15	3	5.34	1.68
Yanbo	31	15	3	5.34	1.66
Jeddah	31	15	3	5.34	1.61
Taif	24	12	2	3.50	1.08
Makkah	24	12	2	3.50	1.21
AL-Baha	24	12	2	3.50	1.27
Bisha	31	15	3	5.34	1.39
Khamis Mushait	31	15	3	5.34	1.57
Abha	31	15	3	5.34	1.58
Najran	31	15	3	5.34	1.38
Sharurah	24	12	2	3.50	1.32
Gizan	31	15	3	5.34	1.48

3. Data

Monthly mean SAT data for the twenty five stations were obtained from the Presidency of Meteorology and Environment in KSA (**Table 2** and **Figure 1**). Twenty five (25) stations cover all regions over the KSA. The selection of these stations is based on the quality and length of their records. The beginning and end of all time series are the years 1978 and 2008, respectively except Al-Ahsa, Al-Baha, Guriat, Makkah, and Shrurah station started in 1985 (**Table 2**). From the monthly SAT values, the wintertime series were calculated for each year by averaging the values SAT of the months December, January, and February. The stations under study are distributed all over KSA, although their spatial density is low and uneven over some parts of the country. Temperature varies over space and time and this highlights the existence of large diversities of temperature over KSA. Besides spatial differences, inter-annual variations of temperature are also occurring. The complex structure of the temperature over KSA derives from the vast area of the country (about, 2,250,000 km^2), its wide latitudinal extent (15.5˚N - 32.5˚N) and its pronounced relief.

4. Methodology

A coefficient of variation (COV) for each individual station has been determined as follows:

Table 2. KSA stations location and record.

No	Name	Latitude (˚N)	Longitude (˚E)	Elevation (m)	Data period	Years
1	**Turaif**	31.68	38.73	852	1978-2008	31
2	**Gurait**	31.40	37.28	504	1985-2008	24
3	**Arar**	30.90	41.14	550	1978-2008	31
4	**Al-Jouf**	29.78	40.98	670	1978-2008	31
5	**Rafha**	29.62	43.49	445	1978-2008	31
6	**Tabouk**	28.37	36.60	770	1978-2008	31
7	**Al-Qaysumah**	28.31	46.13	360	1978-2008	31
8	**Hail**	27.43	41.69	1000	1978-2008	31
9	**Gassim**	26.30	43.76	648	1978-2008	31
10	**Dhahran**	26.25	50.16	22	1978-2008	31
11	**Wejh**	26.20	38.47	20	1978-2008	31
12	**Al-Ahsa**	25.29	49.48	180	1985-2008	24
13	**Riyadh**	24.92	46.72	610	1978-2008	31
14	**Madina**	24.54	39.69	630	1978-2008	31
15	**Yenbo**	24.14	38.06	8	1978-2008	31
16	**Jeddah**	21.71	39.18	18	1978-2008	31
17	**Taif**	21.48	40.55	1455	1978-2008	24
18	**Makkah**	21.43	39.79	273	1985-2008	24
19	**Al-Baha**	20.29	41.64	1655	1985-2008	24
20	**Bisha**	19.99	42.61	1167	1985-2008	31
21	**Khamis Mushait**	18.29	42.80	2047	1978-2008	31
22	**Abha**	18.23	42.66	2100	1978-2008	31
23	**Najran**	17.61	44.41	1213	1978-2008	31
24	**Sharurah**	17.46	47.10	727	1985-2008	24
25	**Gizan**	16.90	42.58	4	1978-2008	31

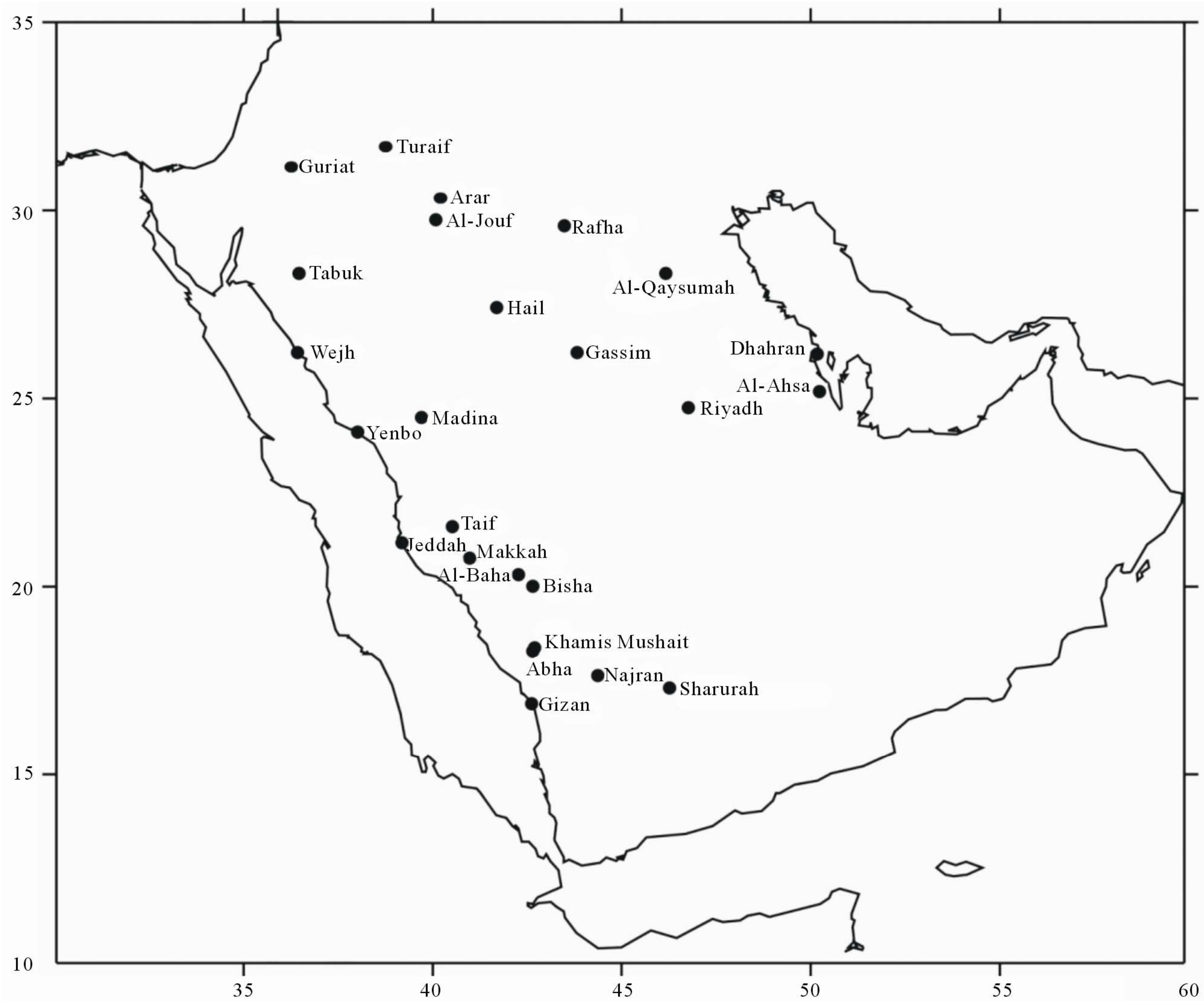


Figure 1. The name and position of KSA stations.

$$\mathrm{COV} = 100 * \mathrm{SD}/\mu .$$

where, SD is the standard deviation and μ is the temporal mean. The evaluation of the trend analysis is based on the [17] method. The 11-year running mean is a filtering method, it removes variations with periods shorter than 10-year in a time series and retains variations of inter-decadal timescales, which are the focus of this study. The symmetry of the weight distribution guarantees no phase shift in the variations within the time series after the filter is applied. The response function of the running mean is similar to that of an ordinary filter, see for example [18]. Also, it has little effect on variations whose frequencies are lower than the cutoff frequency of the filter but has great effect on variations of frequency near its cutoff frequency, for example, the 12-year variation.

The non-parametric Mann-Kendall (M-K) statistical test [19-21] is used to detect any possible trend in the temperature series, and to test whether or not any such trends are statistically significant. A detailed assessment for the testing of climatic data that are unevenly distributed in time and a comparison of methods for estimating the significance level of any trend can be found in a study performed by [22]. The M-K statistical test delivers provides a value that indicates direction (or sign) and the statistical magnitude of the trend in a series.

To visualize the decadal and inter-decadal fluctuations or "persistence" in the behavior of the KSA temperature, cumulative annual means method is used [23]. The advantage of this is to reveal time varying structures in time series. The cumulative annual means time series can be defined as; $y_j = \frac{1}{j}\sum_{i=1}^{j} x_i$, $j = 1, 2, \cdots, N$. Where, x_i is the total annual temperature and N is the number of years of data used. Of course, $y_{j=N} = \overline{x}(N)$.

5. Results and Discussion

5.1. Coefficient of Variation (COV)

In this section, the variability of the wintertime SAT over KSA is explored by examining the coefficient of variation during the study period. The COV results are displayed in **Table 3**, and **Figure 2(a)**. The COV for wintertime SAT decrease gradually from the north to the south of KSA. The higher values occur in the north and northeast of KSA with the highest one at Turaif (13.4%), the northernmost station KSA, while the lowest value of COV of wintertime SAT appears at Gizan (1.9%), the southernmost station in KSA. The higher COV wintertime values over north and northeast are due to the effect of the traveling Mediterranean depressions and their interaction with the inverted V-shaped trough of the Sudan low. **Table 3** illustrates also that the COV values ranged from 1.9% at Gizan to 13.4% at Turaif and the average of the COV of wintertime SAT is usually about 6%. The higher and lower values of the standard deviations (SD) are associated with the higher and lower values of the COV (**Table 3**). Generally, the COV of wintertime SAT is high. Therefore the winter SAT is less stable over KSA. The relationship between COV and latitude is positive and highly significant (r = 0.8, 99% significant level, **Figure 2(b)**) while it is negative and not significant with longitude (r = –0.24, **Figure 2(c)**). So, the COV values increase with increasing latitude (the values of COV at the north stations are more than those at the south) and increase with decreasing longitudes (the values of COV at the west stations are more than those at the east). This result is reasonable in winter season where the north of KSA has considerable difference of temperature than in the south while the difference in temperature from west to east is small.

Table 3. The standard deviation, mean coefficient of variation and non-linear trend (derived by Mann-Kendall statistical test) of wintertime SAT for KSA stations.

Station	Latitude (°N)	Longitude (°E)	SD	Mean	COV	Trend
Turaif	31.68	38.73	1.11	8.34	13.4	0.10
Guriat	31.40	37.28	1.00	9.56	10.4	0.10
Arar	30.90	41.14	1.15	9.96	11.5	0.10
Al-Jouf	29.78	40.98	1.33	10.70	12.4	0.17
Rafha	29.62	43.49	1.18	11.48	10.3	0.10
Tabouk	28.37	36.60	1.15	11.94	9.6	0.10
Al-Qqaysumah	28.31	46.13	1.21	13.02	9.3	0.18
Hail	27.43	41.69	1.21	11.69	10.3	0.32*
Gassim	26.30	43.76	1.23	13.99	8.8	0.20
Dhahran	26.25	50.16	0.96	16.59	5.8	0.40**
Wejh	26.20	38.47	0.93	19.74	4.7	0.18
Al-Ahsa	25.29	49.48	0.88	16.23	5.5	0.10
Riyadh	24.92	46.72	1.07	15.87	6.8	0.20
Madina	24.54	39.69	1.19	19.15	6.2	0.21
Yanbo	24.14	38.06	1.13	21.31	5.3	0.21
Jeddah	21.71	39.18	0.89	23.66	3.8	0.10
Taif	21.48	40.55	0.83	16.29	5.1	0.32*
Makkah	21.43	39.79	0.99	24.62	4.0	0.32*
Al-Baha	20.29	41.64	0.71	16.55	4.3	0.52**
Bisha	19.99	42.61	0.99	18.64	5.3	0.41**
Khamis Mushait	18.29	42.80	0.86	14.65	5.9	0.75**
Abha	18.23	42.66	0.57	13.81	4.1	0.52**
Najran	17.61	44.41	0.95	18.45	5.1	0.40**
Sharurah	17.46	47.10	0.89	20.77	4.3	0.32*
Gizan	16.90	42.58	0.51	26.38	1.9	0.48**

*Significant at level 95%; **Significant at level 99%.

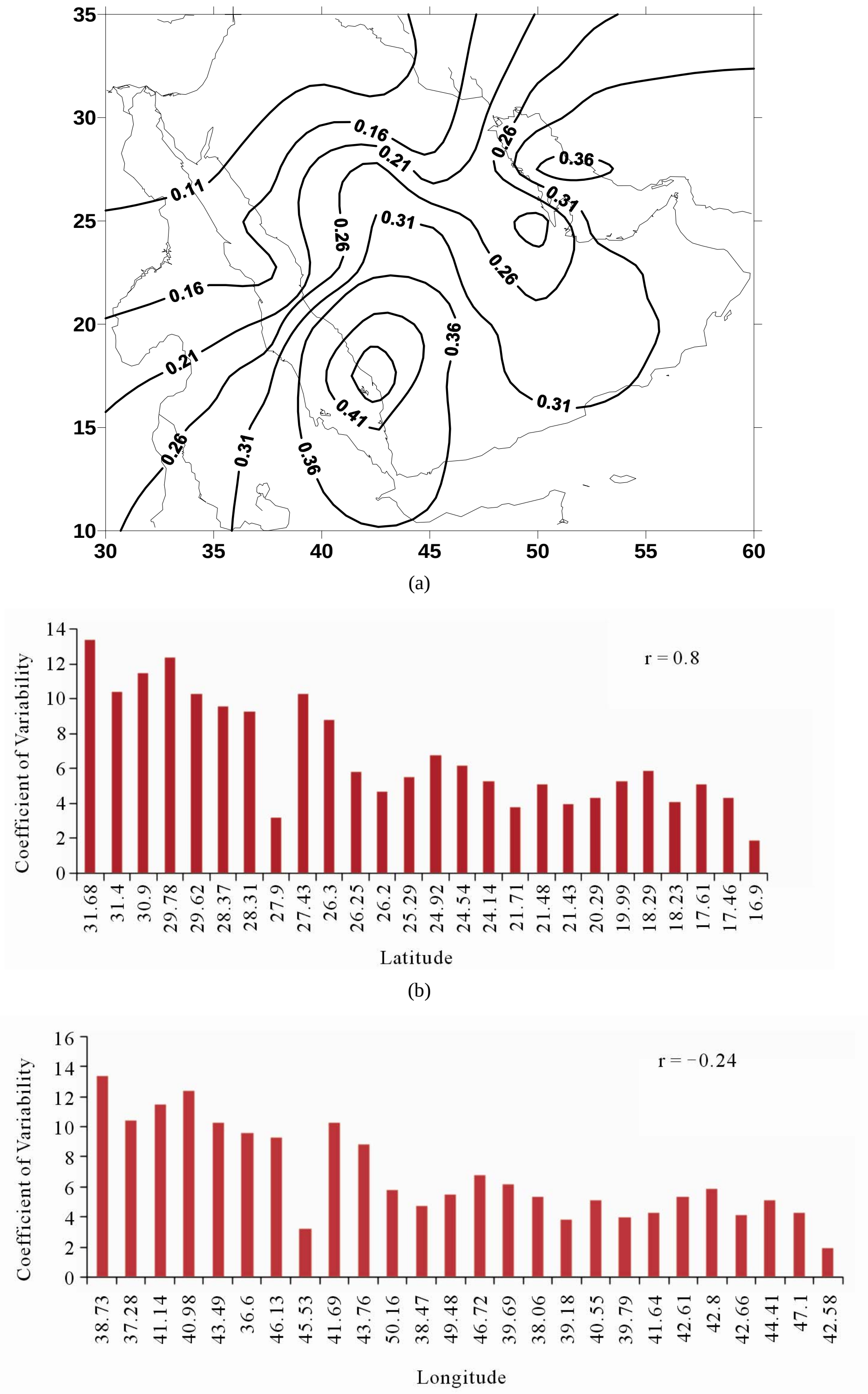


Figure 2. Coefficient of variation pattern (COV) of wintertime SAT for 25 KSA stations (a); relationship between COV and Latitude (b); and relationship between COV and Longitude (c) (r means correlation coefficient).

5.2. Trend Analysis

The wintertime SAT series for the KSA stations under study here are investigated to determine their trends. The trend analysis is performed by means of both simple and robust tools. The evaluation of the trend is based on the Mann-Kendall (M-K) statistical test, which makes no assumption regarding probability distribution for the original data, the data are tested for significance using a standard normal distribution. The spatial distribution pattern is not complex, even though the resultant M-K statistical test give both negative and positive trends. **Table 3** and **Figure 3** show the M-K statistical test for the 25 sites in KSA. The values of M-K statistical test were computed according to [19]. Positive trends (warming) are observed over all stations. **Table 3** and **Figure 3** indicate that the trends are high and significant for the southern and middle regions stations.

Further insight into the results are gained through the [17] method. Persistent phases of alternating increase or decreases in temperature, which vary in length, are recognizable within the time series for wintertime SAT. **Figure 4** illustrates the behavior of the temperature during the available data period of each station. It is evident from **Figure 4** that, from the first period under study up to about 1983, a noticeable decrease in SAT occurs at all stations. The decrease in mean wintertime SAT reaches about 1˚C but it is not uniform across the areas under investigation. Another noticeable decrease of more than 1˚C is evident for all stations round 1987 and 1988. The results reveal that there has been an increasing in wintertime SAT (warming) at most stations in the last two decades beginning around 1993 and 1994 and continuing up to the end of the period under study. Also, an important increase of SAT in southern region (Bisha, Khamis-Mushait, Abha, Najran, Sharurah and Gizan stations, **Figure 4(c)**) from 1984 up to the end of the period under study (2008). These trends are in general consistence with trends in the global mean SAT since the late 19th century. The most probable cause of the observed warming in recent climate change is a combination of internally and externally forced natural variability and anthropogenic sources.

5.3. Cumulative Annual Mean (CAM)

In this section, we analyzed the long-term behavior of the wintertime SAT through CAM. The CAM can be detected the climatic shift in wintertime SAT [23]. Persistent phases of alternating increase or decrease of the temperature, which vary in length, are recognizable in the time series of the wintertime SAT. Moreover, to visualize the decadal and inter-decadal fluctuations present in the wintertime SAT, CAM is used, because they can reveal time varying structures in time-series that cannot be obtained using the original time series. The results of CAM are shown in **Figures 5**. The CAM patterns for all stations approximately have the same behavior throughout the observational period with an exception three stations (Wejh, Khamis Mushait and Sharurah, **Figures 5(b)** and **5(c)** respectively). In general, they show a negative temperature trend (cooling) during the first period (1978-1982) followed by a positive trend (warming) until the year of 1988 followed by another decrease (cooling) during the period from 1988 up to 1992. A gradual warming is found from 1993 up to the end of the period 2008. The average warming trend evaluates approximately by about 0.5˚C. On other hand, the average cooling trend evaluates by 1.0˚C in the period (1978-1982) and 0.3˚C in the period (1988-1992).

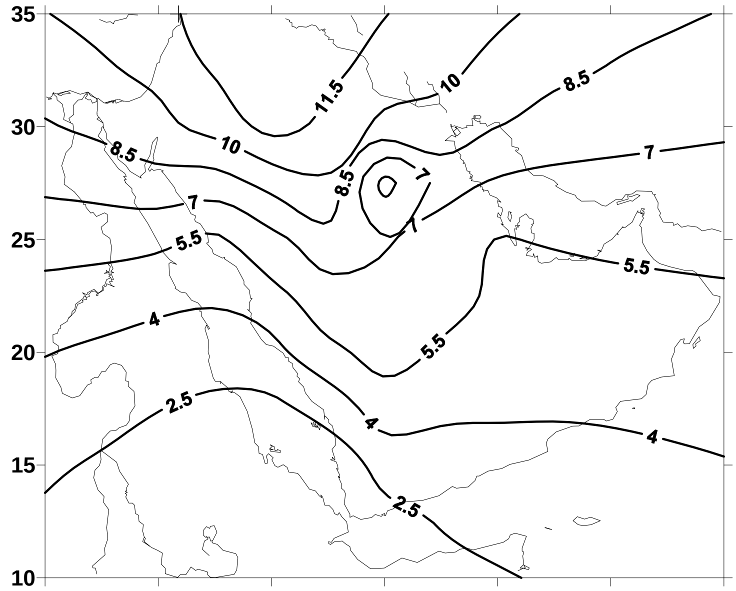
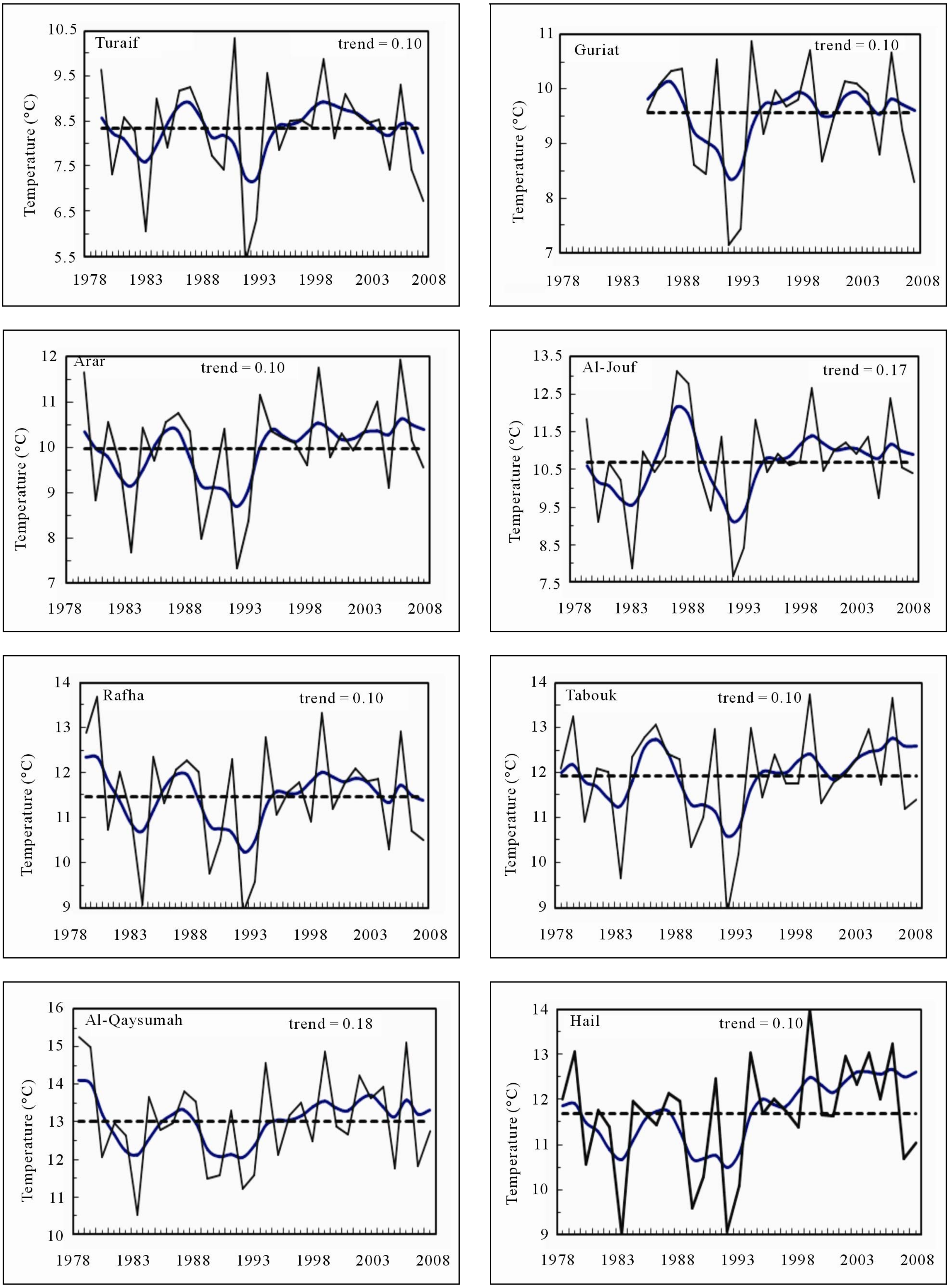
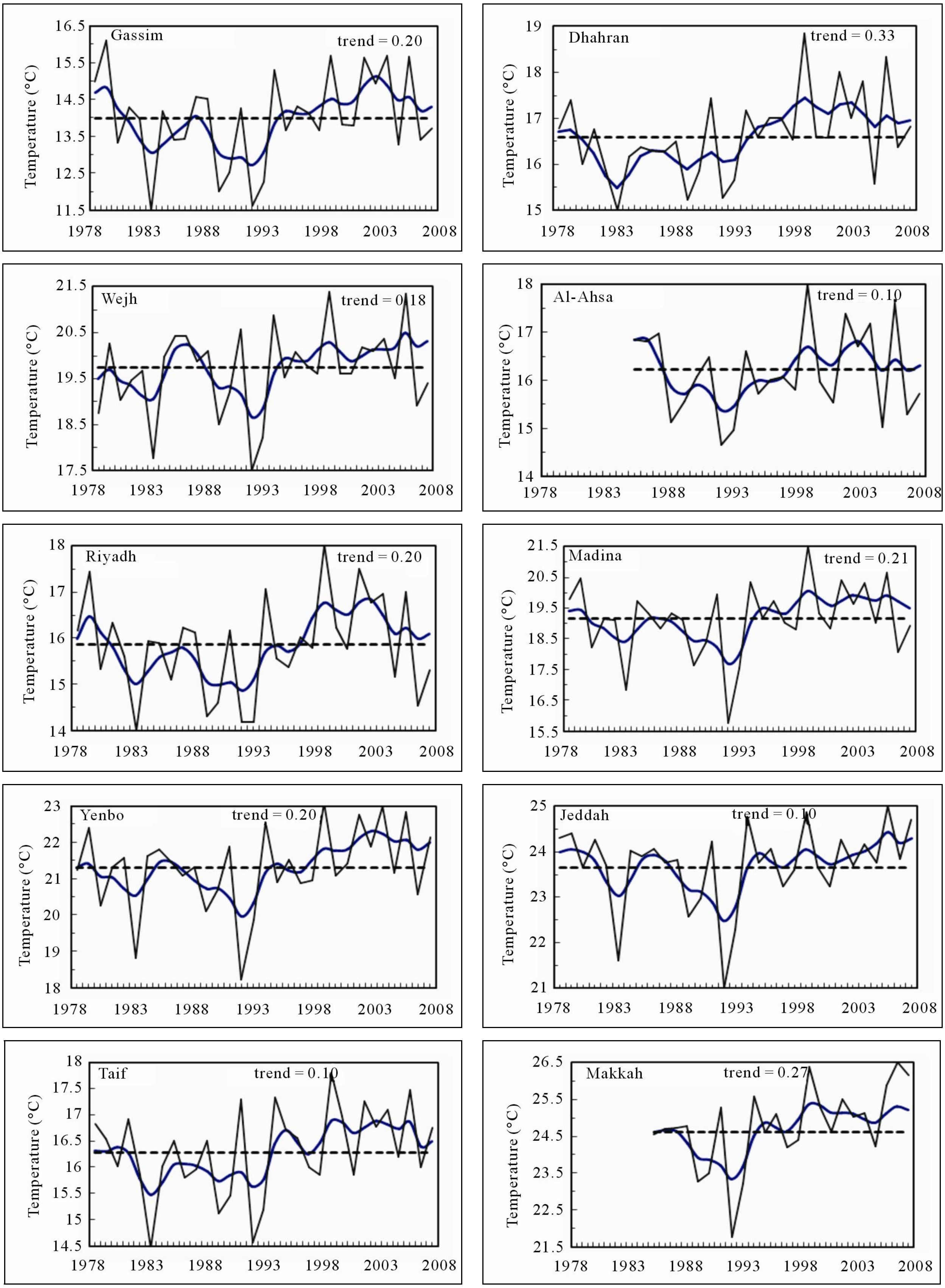


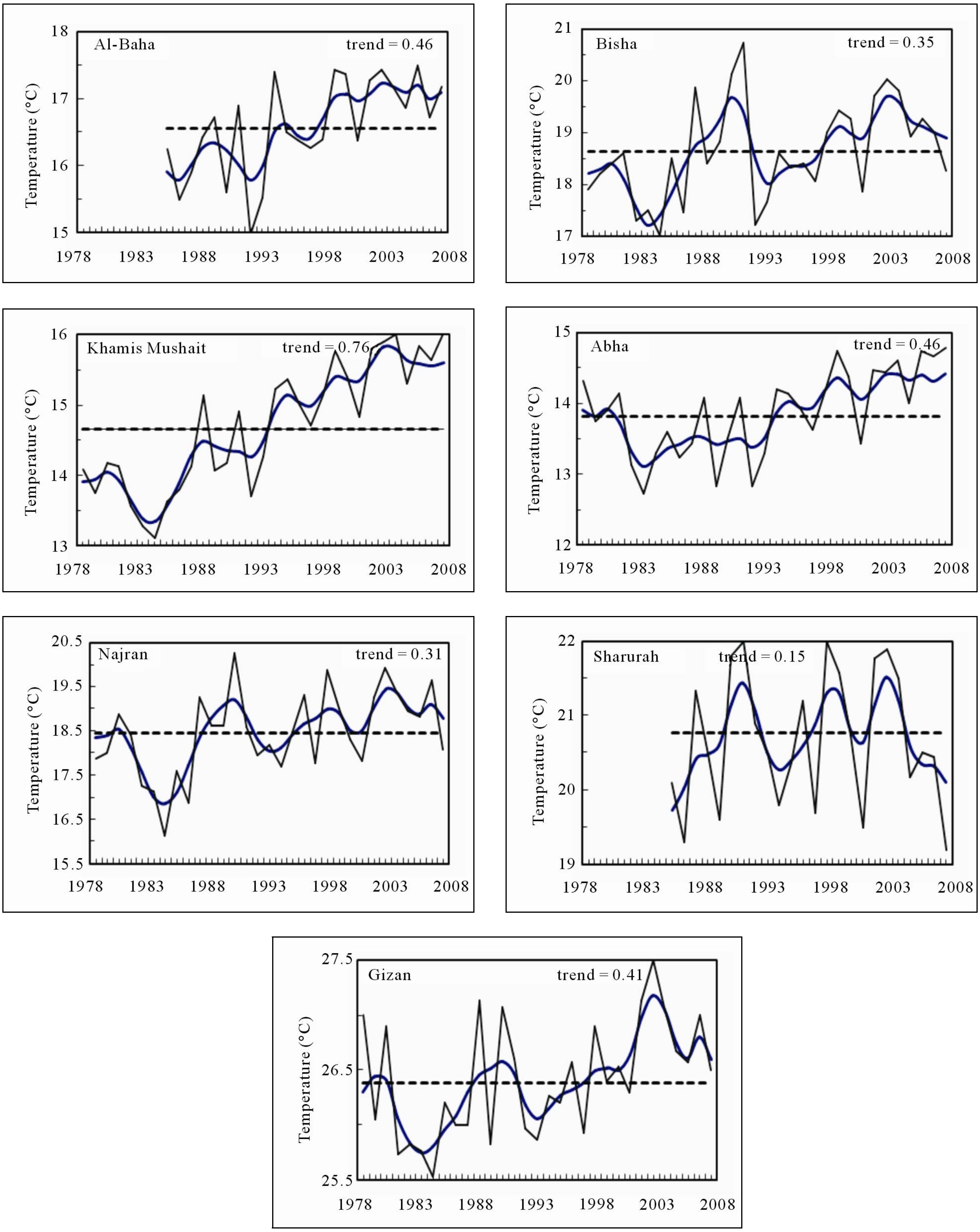
Figure 3. Trend pattern of wintertime SAT for 25 KSA stations by using M-K statistic test (trend values above 0.30 are statistically significant at 95% confidence level).


Turaif
trend = 0.10
Guriat
trend = 0.10
Arar
trend = 0.10
Al-Jouf
trend = 0.17
Rafha
trend = 0.10
Tabouk
trend = 0.10
Al-Qaysumah
trend = 0.18
Hail
trend = 0.10
Temperature (°C)
1978 1983 1988 1993 1998 2003 2008

(a)


Gassim
trend = 0.20
Dhahran
trend = 0.33
Wejh
trend = 0.18
Al-Ahsa
trend = 0.10
Riyadh
trend = 0.20
Madina
trend = 0.21
Yenbo
trend = 0.20
Jeddah
trend = 0.10
Taif
trend = 0.10
Makkah
trend = 0.27
Temperature (°C)
1978
1983
1988
1993
1998
2003
2008

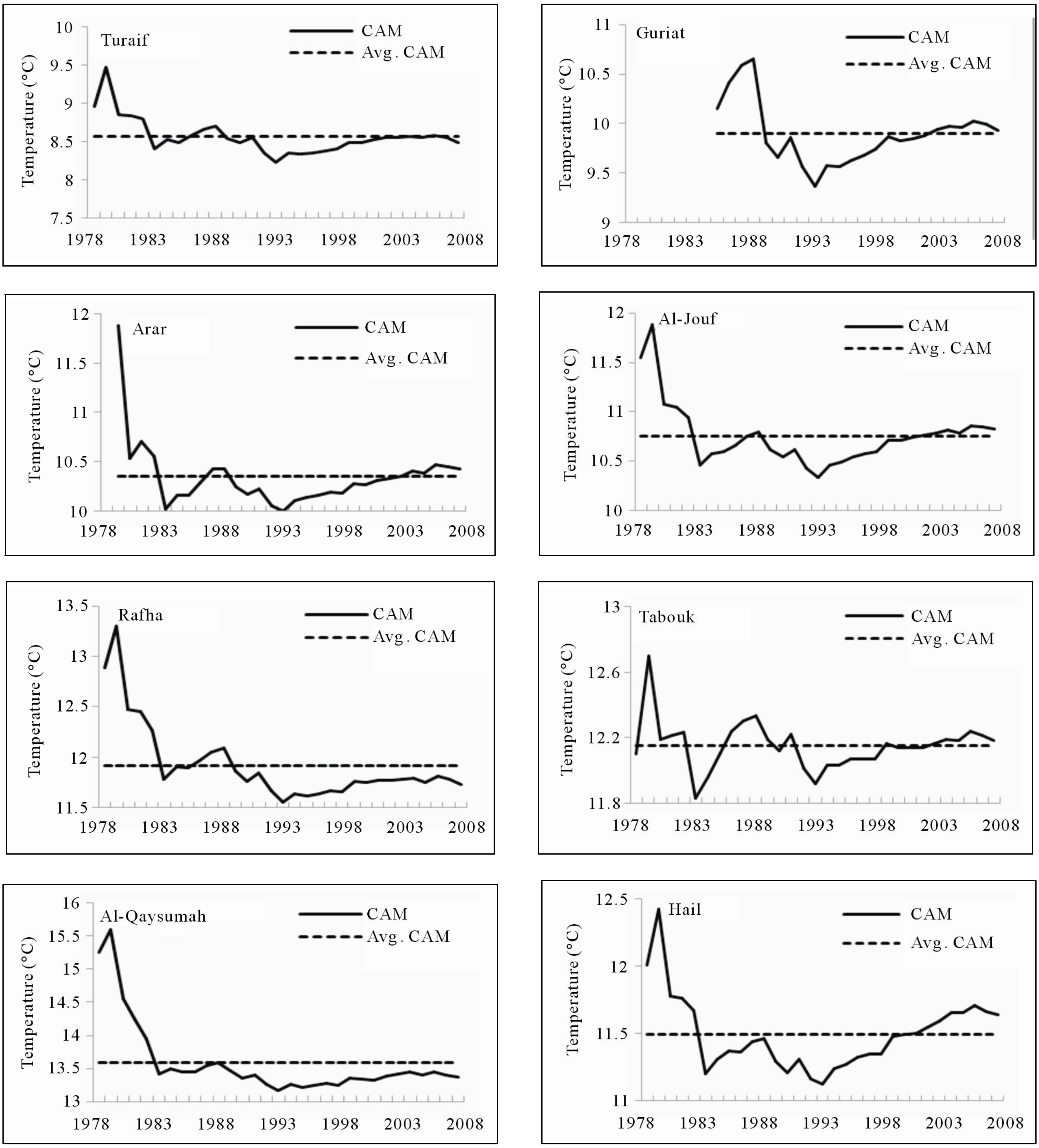
(b)



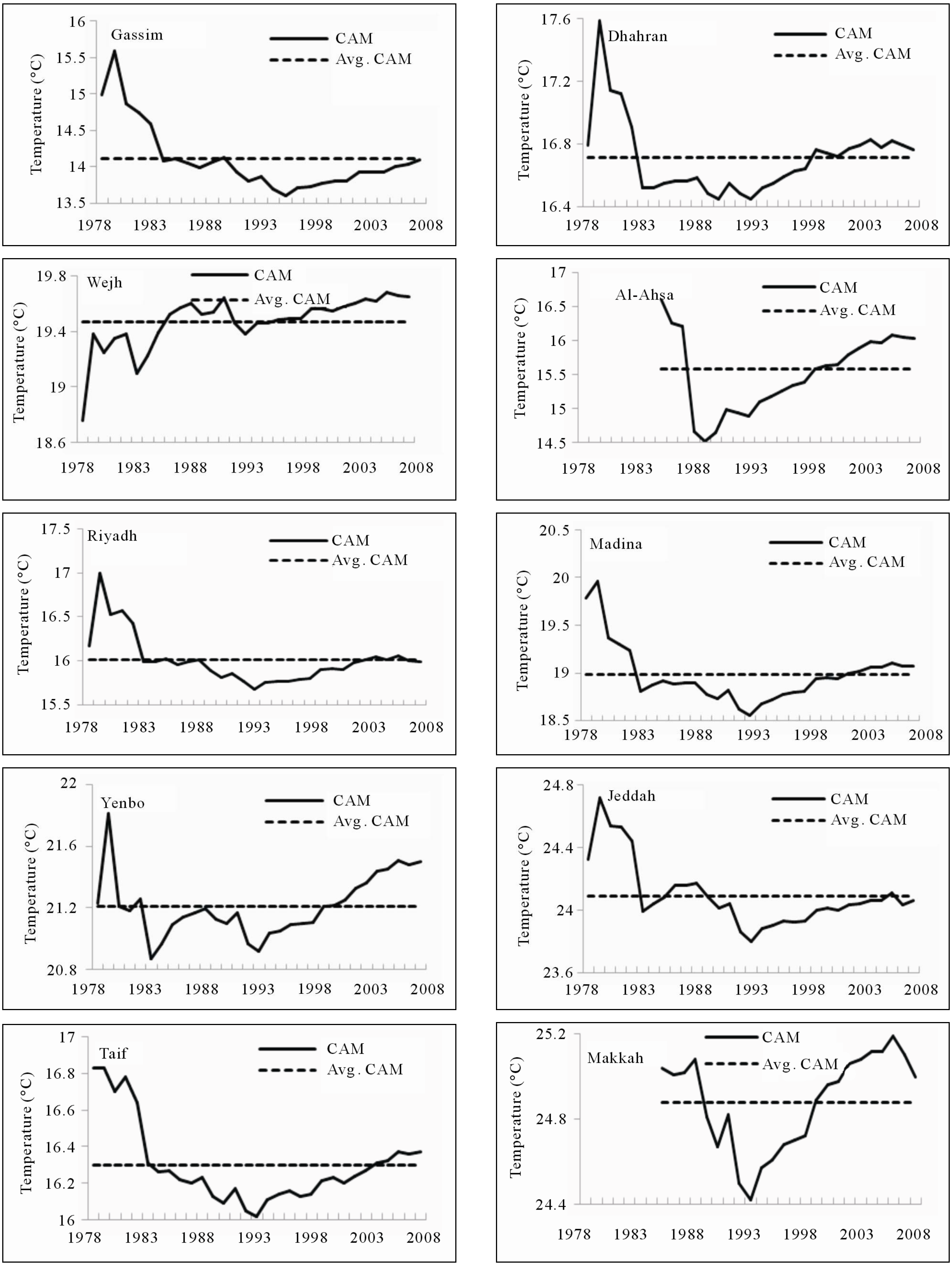
(c)

Figure 4. (a) Trend analysis of the winter surface temperature of the stations Turaif, Guriat, Arar, Al-Jouf, Rafha, Tabouk, Al-Qaysumah, and Hail (dotted line is the mean, dotted smoothed curve is a trend, solid curve is the observation data; (b) As in Figure 2(a) but for the stations Gassim, Dhahran, Wejh, Ahsa, Riyadh, Madina, Yanbo, Jeddah, Taif, and Makkah; (c) As in Figure 2(a) but for the stations Al-Baha, Bisha, Khamis-Mushait, Abha, Najran, Sharurah and Gizan.

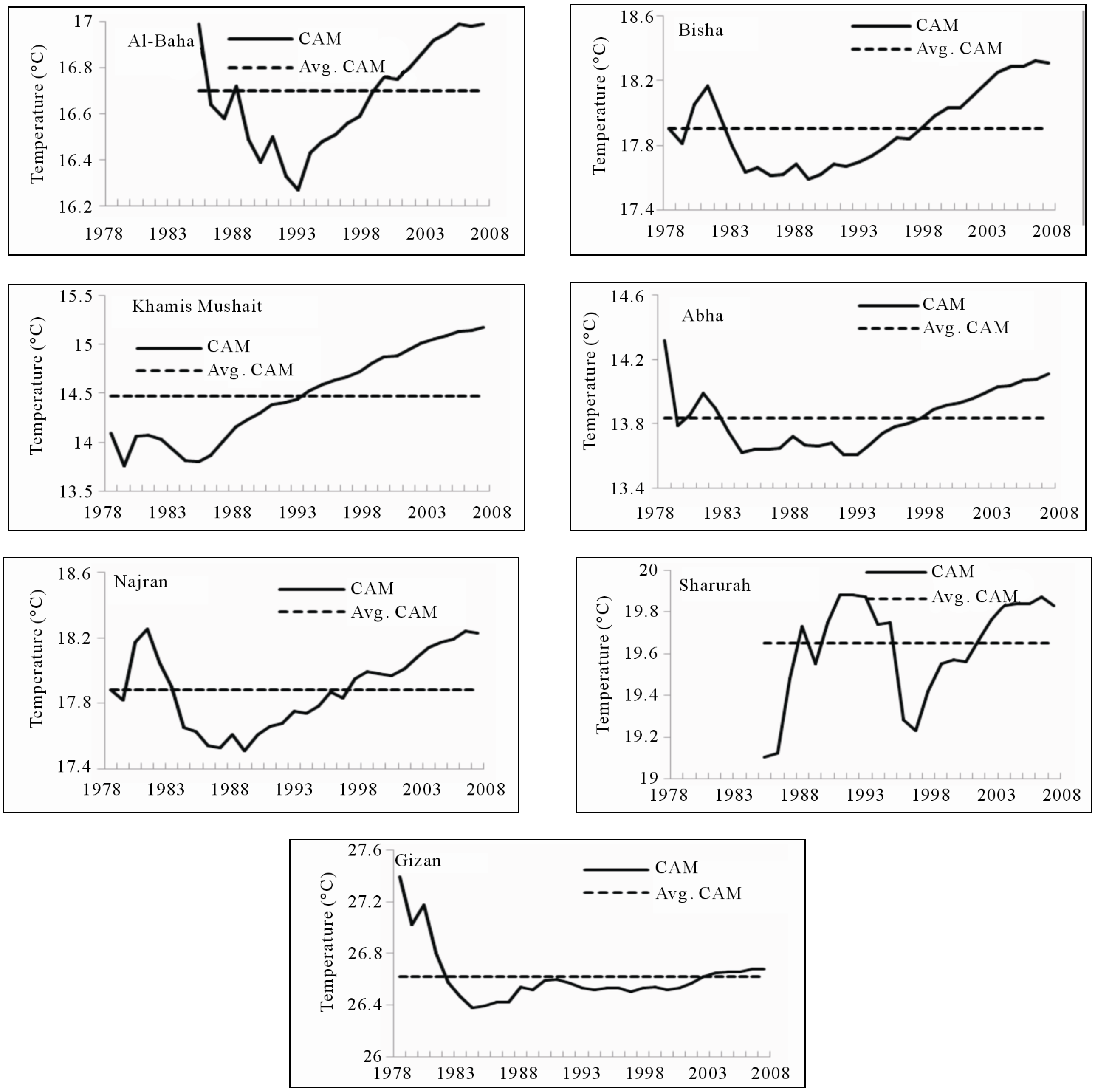
The change point or climatic shift in wintertime SAT from cooling to warming is the more pronounced feature in the first half of 1990's in all stations with an exception southern region (Khamis Mushait, Abha, Najran, Sharurah, and Gizan stations), **Figure 5**. The climatic shift in wintertime SAT in southern region, **Figure 5(c)** begin in the mid of the 1980's. Also, in **Figure 5** we compare y_j, $j = 1, 2, \| N$ with $\bar{y}$. The most important feature here is the change, from below $\bar{y}$ to above $\bar{y}$ during the second half of the 1990's (1997) in the most stations with an exception of Guriat, Tabouk, Taif and Sharurah stations. In the first of 21's century the change from below $\bar{y}$ to above $\bar{y}$ in these stations is found. The changes of the SAT tend to warming after the year 1997 with a rate of 0.03˚C/year approximately. These results seem to coincide with the [6] scientific report. Globally, it is



(a)


Gassim
Dhahran
Wejh
Al-Ahsa
Riyadh
Madina
Yenbo
Jeddah
Taif
Makkah
CAM
Avg. CAM
Temperature (°C)
1978
1983
1988
1993
1998
2003
2008

(b)



(c)

Figure 5. (a) The cumulative annual mean (CAM, solid curve) time series and the averaged CAM (dashed line) in Turaif, Guriat, Arar, Al-jouf, Rafha, Tabouk, Al-Qaysumah, and Hail; (b) As Figure 5(a) but for Gassim, Dharhan, Wejh, Al-Ahsa, Riyadh, Madina, Yenbo, Jeddah, Taif and Makkah; (c) As in Figure 5(a) but for the stations Al-Baha, Bisha, Khamis-Mushait, Abha, Najran, Sharurah and Gizan.

very likely that the 1990's was the warmest decade and 1998 the warmest year in the instrumental record, since 1861 [6].

6. Conclusions

Variability in the wintertime SAT over KSA has been investigated throughout the available data period from twenty five stations. In order to obtain a clear and representative picture wintertime SAT in KSA, the coefficient of variation (COV) is adopted to assess the durability and stability of the SAT in different regions of KSA. We found that the COV of wintertime SAT over KSA ranged from 1.9% to 13.4%, and it is usually about 6%. Also we concluded that the reason of the spatial varia tions of COV is due to the effect of the traveling Mediterranean depressions and its interaction with the inverted V-shape trough of the Sudan low. Relationship between COV and latitudes is highly significant, while with longitudes is not significant. Mann-Kendall (M-K) statistical test illustrates that positive trends (warming) in wintertime SAT series occurs over the all stations and the trends of wintertime SAT are significant at mid and southern region of the KSA.

The use of the [17] method for surface temperature is provide to be fruitful approach to studying inter-annual climate fluctuations, because they reveal time varying structure in the raw data or in the more traditional statistical analyses. Examination of the [17] method wintertime SAT over KSA has revealed support for the notion of extended "persistence" over several years, even though simple year-to-year persistence may be evident. The wintertime SAT of the area is characterized by warm periods 1993-2008 at all regions of KSA stations, and 1984-2008 in southern region stations. While cooling in the wintertime SAT appears for the short period of about 5 years, 1978-1982 and 1988-1992. A warm period was not uniform, continuous or of the same order. Recent warming has only occurred during the last two decades at most stations. These trends are in general consistence with the global trends in the mean surface temperature. The most probable cause of the observed warming in the recent climate change is a combination of internally and externally forced natural variability and anthropogenic sources.

Regarding to the analysis of CAM, one can see that, the CAM patterns for all stations approximately have the same behavior throughout the observational period. Fluctuation every 5 years from cooling to warming and in reverse is found in the most stations from the beginning period up to under study up to 1992. A gradual warming is found from 1993 up to the end of the period 2008. The average warming trend evaluates approximately by about 0.5˚C. On other hand, the average cooling trend evaluates by 1.0˚C in the period (1978-1982) and 0.3˚C in the period (1988-1992). The climatic shift in wintertime SAT from cooling to warming is found in the first half of 1990's in all stations with an exception southern region. In southern region the climatic shift in wintertime SAT, begin in the mid of the 1980's. Moreover, the most important feature is the change, from below average of CAM to above average of CAM, during the second half of the 1990's in the most stations. These results seem to coincide with the [6] scientific report. Globally, it is very likely that the 1990's was the warmest decade and 1998 the warmest year in the instrumental record, since 1861 [6].

7. Acknowledgements

The authors are grateful for being enabled to use monthly mean KSA station temperature series from Presidency of Meteorology and Environment in Kingdom of Saudi Arabia (KSA). We are indebted to the faculty of meteorology and environmental, for making available the computer and other facilities in this work.

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